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Drought effects on yield and its components in Indian mustard (*Brassica juncea* L.)

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With 3 tables

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Abstract

Effects of drought on yield and yield components were investigated during the spring season 2000–2001 by growing 14 Indian mustard genotypes under irrigated and rain-fed conditions at Bharatpur and Jobner. A disease and pest management schedule was followed when required. The drought susceptibility index (DSI) for seed yield and component characteristics was calculated to characterize the relative tolerance of genotypes. Plant height, primary branches, secondary branches per plant, 1000-seed weight and seed yield were reduced under rain-fed conditions. The top five genotypes at Bharatpur that showed tolerance to moisture stress for seed yield, as indicated by their lowest DSI, were, in descending order PSR-20, PRO-97024, JMMWR-941, IS-1787 and PCR-7, whereas at Jobner these were JMMWR-941, RC-1446, PSR-20, RH-819 and 'Varuna'. Of these, PSR-20 and JMMWR-941 were among the top six at both locations. These genotypes also showed relatively low DSI for one or more characteristics, such as primary branches per plant, secondary branches per plant, harvest index and seed : husk ratio. Genotypes with the lowest DSI, particularly for seed yield at both locations, would serve as useful donors in the breeding programme for improving the drought tolerance of existing Indian mustard cultivars.

Key words: *Brassica juncea* — drought — susceptibility index — seed yield — oil content

Rapeseed-mustard crops in India account for about 21.6% and 23.2% of the total oilseed harvested area and production, respectively (Anonymous 2004). Indian mustard is predominantly grown on nearly 90% of the total harvested area, covering up to 7.0 m ha. Nearly 37% of the total rapeseed-mustard area is rain-fed, where the crop is severely affected by drought, resulting in acute yield losses particularly in the drought-prone areas of Eastern and Western India which are populated largely by resource poor farmers with small land holdings. The effect of drought depends on the time of its occurrence, duration and intensity. Mustard genotypes with drought tolerance trait(s) yielded better than those without such trait(s) under water stress conditions (Singh et al. 1988). Therefore, investigating the effects of drought on yield and yield components in Indian mustard is very important for identifying drought-tolerant traits that can be incorporated into high-yielding varieties. This study is aimed at investigating the effects of drought on a wide range of genotypes of Indian mustard and identifying suitable selection criteria for drought tolerance.

Materials and Methods

Plant material and experimental locations: Fourteen genotypes of Indian mustard, *Brassica juncea* L. (IS-1787, BE-3121, RC-53, PRO-97024, RC-1446, DIR-673, RC-5, EC-347852, JMMWR-941, PSR-20, 'Varuna', PCR-7, RN-393 and RH-819) were grown during the spring season (October–April) of 2000–2001 at two locations in Rajasthan (India), Bharatpur and Jobner, which are approximately 230 km apart. The rainfall during the cropping season, October–April, was 0.5 and 0.9 mm at both locations, respectively, as this is dry period in these parts of India.

Experimental design: Each location consisted of rain-fed and irrigated trials separated by at least 5 m to avoid interference. Each trial was arranged in a randomized complete block design with three replications. Trial plots consisted of four rows, each 5 m long. Distances between rows and plants within each row were maintained at 30 and 10 cm, respectively. The irrigated trials received two irrigations at 40 and 80 days after sowing. At the time of sowing, 40 kg/ha N and 20 kg/ha P_2O_5 were given to each plot in both trials. A disease and pest management schedule was followed as and when required.

Observations and evaluation: Five plants from each plot were randomly chosen for recording observations on their height, primary and secondary branches per plant, 1000-seed weight (g), harvest index (%) and seed : husk ratio (Bharatpur). Observations on seed yield were recorded on a plot basis. Seed : husk ratio was calculated as weight of seeds/weight of husk. The effect of drought was assessed as percentage reduction in mean performance of a characteristic under rain-fed conditions relative to the performance of the same trait under irrigated conditions. A drought susceptibility index (DSI) for seed yield and its components was calculated using the following formula (Fischer and Maurer 1978):

$$\mathrm{DSI} = \frac{(1 - Y_s/Y_i)}{(1 - \bar{Y}_s/\bar{Y}_i)},$$

where Y = mean of a characteristic; $\bar{Y}$ = experimental mean; s = moisture stress and i = irrigated environment.

Data analysis: Analysis was done using the GENSTAT statistical package, 7th Edition (Payne 2000). Where residual variances were comparable across trials, Analysis of variance (ANOVA) was used to analyse the data. The main effects of location, treatments and genotypes were fitted with all two- and three-way interactions, also allowing for variation due to replicates within trials. For seed yield and harvest index, the residual variance differed greatly between trials. For these cases, the data were fitted to a mixed model with location,

Table 1: Plant height and primary branches under rain-fed and irrigated conditions for different genotypes and their DSI at Bharatpur and Jobner (DSI values are not included in the statistical analysis)

	Plant height (cm)						Primary branches					
	Bharatpur			Jobner			Bharatpur			Jobner		
Genotype	Rain-fed	Irrigated	DSI	Rain-fed	Irrigated	DSI	Rain-fed	Irrigated	DSI	Rain-fed	Irrigated	DSI
IS-1787	126.7	163.9	1.32	140.5	150.1	0.74	3.47	4.93	1.61	4.67	5.67	1.64
BE-3121	128.7	175.5	1.55	123.5	139.4	1.32	4.53	6.50	1.64	5.20	7.30	2.67
RC-53	138.4	169.7	1.07	127.0	136.2	0.78	4.60	5.87	1.17	5.97	6.77	1.10
PRO-97024	140.2	160.9	0.75	131.5	148.3	1.31	4.00	5.40	1.41	4.47	5.77	2.09
RC-1446	136.9	158.1	0.78	130.9	151.6	1.58	4.07	4.73	0.76	6.77	7.53	0.94
DIR-673	140.7	174.5	1.13	123.8	132.8	0.79	4.73	4.73	0.00	5.17	7.03	2.46
RC-5	144.8	177.2	1.06	124.2	143.6	1.56	4.60	5.30	0.72	7.17	7.50	0.41
EC-347852	132.2	174.6	1.41	115.5	133.7	1.58	4.47	6.07	1.43	7.23	7.47	0.29
JMMWR-941	141.6	167.4	0.90	124.7	128.6	0.35	3.67	4.87	1.34	5.70	6.17	0.70
PSR-20	138.1	162.9	0.89	130.2	139.5	0.77	4.07	5.33	1.29	6.37	6.53	0.24
'Varuna'	138.1	160.5	0.81	123.7	127.2	0.32	3.53	4.27	0.93	7.27	7.40	0.17
PCR-7	141.2	166.1	0.87	117.5	128.4	0.98	4.27	3.93	−0.46	5.73	5.73	0.00
RN-393	160.1	177.7	0.58	121.4	127.6	0.56	4.20	5.63	1.38	6.17	6.33	0.24
RH-819	153.1	179.5	0.86	143.4	158.9	1.13	5.40	5.47	0.07	5.57	6.30	1.08
Mean	140.1	169.2	1.00	127.0	139.0	0.98	4.26	5.22	0.95	5.96	6.68	1.00
Mean LSD[1]	21.3						0.98					
df	104						104					

[1]Mean LSD for rain-fed/irrigated mean values for both locations.
df, degrees of freedom; DSI, drought susceptibility index.

treatment and genotype effects and interactions fitted as fixed terms, and with the effects of replicates within trials fitted as random, and with heterogeneity allowed between trials. This model is a simple extension of the ANOVA model to account for heterogeneity between trials, and was fitted using Restricted Maximum Likelihood (REML) estimation (Patterson and Thompson 1971, Payne 2000). Mean values for genotype × location × treatment combinations were predicted from the fitted models, with LSDs calculated from the average standard error of difference (SED) and residual degrees of freedom (104 df for variables measured at both sites, and 52 df for variables measured at one site only). *F*-statistics were used to test genotype main effects and interactions from the ANOVA analyses, and Wald statistics were used for the REML analyses. Values of DSI were calculated for each genotype at each site using the predicted mean values. For the variables DSI and percentage change in each character due to irrigation, the simple correlation coefficient (Gomez and Gomez 1984) was calculated between variables within sites and correlation within variables across sites.

Results

Analysis of variance

Significant differences ($P < 0.05$) among the genotypes for primary branches and secondary branches/plant, 1000-seed weight, seed yield and harvest index were revealed by the ANOVA/REML analyses. Location × genotype interactions were also significant for these characters. Treatment × genotype interactions were significant for primary and secondary branches/plant, seed yield, harvest index and seed : husk ratio. Location × treatment × genotype interactions were non-significant except for harvest index.

Performance of genotypes

Performance of most of the agro-morphological characteristics (s), except for harvest index, seed : husk ratio and oil content, was reduced under rain-fed conditions when compared with irrigated conditions at both locations (Tables 1–3). At Bharatpur, there was a substantial reduction in plant height (12.9–26.6%), primary branches per plant (7.3–32.5%) and secondary branches per plant (15.0–76.5%) but with the exception of DIR-673, which exhibited increased secondary branches per plant (39.4–67.4%) at both locations under rain-fed conditions. Mean reduction in 1000-seed weight under rain-fed conditions was marginally higher at Bharatpur (6.0%) when compared with Jobner (5.3%). However, genotype DIR-673 exhibited increased seed weight under rain-fed conditions at both locations, whereas few others had increased seed weight at either Bharatpur or Jobner. The seed yield reduction under rain-fed conditions at Bharatpur varied from 12.6% in PSR-20 to 60.0% in RC-1446. At Jobner, the reduction was between 4.3% in RH-819 to 29.9% in RC-5, except for genotypes PSR-20, RC-1446 and JMMWR-941, which had increased seed yield by 0.9%, 2.2% and 3.3%, respectively. The harvest index at both locations was increased under rain-fed conditions, except for genotype EC-347852 at Bharatpur and genotypes IS-1787, DIR-673, RC-5, RN-393 and RH-819 at Jobner.

Drought susceptibility index

The DSI for the various characteristics is presented in Tables 1–3. Large DSI values indicate greater drought susceptibility (Winter et al. 1988). Differences in DSI between genotypes were observed for all characteristics under investigation in this study. At both locations, the mean values of DSI for plant height, secondary branches per plant, 1000-seed weight and seed yield were close to or below 1, indicating the relative tolerance of these traits to drought. Higher DSI values observed for seed : husk ratio (at Bharatpur) and harvest index (mainly at Jobner) indicated that these characteristics are relatively more prone to drought stress. PSR-20 and JMMWR-941 were among the top genotypes with the lowest DSI for seed yield at both locations, thereby indicating that the genotypes were drought-tolerant. Furthermore, these genotypes also showed relatively low DSI for one or more characteristics, such as plant height, primary branches per

Table 2: Secondary branches, 1000-seed weight and seed yield under rain-fed and irrigated conditions for different genotypes and their DSI at Bharatpur and Jobner (DSI values are not included in the statistical analysis)

Genotype	Secondary branches						1000-seed weight (g)						Seed yield (kg/ha)					
	Bharatpur			Jobner			Bharatpur			Jobner			Bharatpur			Jobner		
	Rain-fed	Irrigated	DSI	Rain-fed	Irrigated	DSI	Rain-fed	Irrigated	DSI	Rain-fed	Irrigated	DSI	Rain-fed	Irrigated	DSI	Rain-fed	Irrigated	DSI
IS-1787	3.33	7.73	1.31	4.70	6.27	1.94	5.23	5.00	−0.84	3.40	3.43	0.17	1458	2083	0.70	911	1046	1.05
BE-3121	4.77	10.67	1.27	9.37	10.67	0.95	4.47	4.27	−0.84	3.07	3.57	2.46	1070	1806	0.95	1015	1281	1.70
RC-53	5.20	10.13	1.12	10.67	10.20	−0.36	4.73	5.07	1.18	3.97	4.40	1.73	1000	2055	1.20	973	1034	0.48
PRO-97024	2.33	7.53	1.59	7.50	9.37	1.55	4.87	4.73	−0.51	3.43	3.90	2.11	1417	1961	0.65	970	1256	1.86
RC-1446	3.93	6.27	0.86	12.60	13.50	0.52	5.27	5.43	0.55	3.67	3.83	0.76	889	2222	1.40	1083	1059	−0.19
DIR-673	7.77	4.60	−1.58	14.43	10.33	−3.08	5.07	4.53	−2.11	4.10	4.03	−0.29	1242	2174	1.00	1031	1256	1.46
RC-5	2.57	5.17	1.16	8.80	11.73	1.94	4.93	5.93	3.03	4.43	4.53	0.39	1042	2260	1.26	851	1214	2.44
EC-347852	5.73	8.13	0.68	12.63	13.27	0.37	3.53	4.53	3.96	3.40	3.60	0.98	1083	2111	1.14	870	1173	2.11
JMMWR-941	3.93	7.33	1.07	8.33	12.83	2.72	5.23	5.53	0.96	3.93	4.00	0.29	1303	1839	0.68	1181	1143	−0.27
PSR-20	5.67	7.67	0.60	8.17	10.53	1.74	4.00	4.43	1.75	3.63	3.27	−1.97	1664	1903	0.29	1071	1062	−0.07
'Varuna'	4.53	5.87	0.52	11.33	12.83	0.91	5.13	6.03	2.68	3.53	4.17	2.67	1312	2778	1.23	969	1022	0.42
PCR-7	3.33	4.03	0.40	10.57	10.33	−0.18	5.37	5.80	1.34	3.07	3.83	3.51	1688	2750	0.90	939	1101	1.20
RN-393	3.10	9.30	1.53	8.40	13.43	2.91	4.43	5.07	2.25	3.60	3.47	−0.67	1063	1986	1.09	964	1079	0.87
RH-819	2.00	8.53	1.76	8.40	10.70	1.67	5.13	5.00	−0.48	3.60	3.87	1.21	938	2078	1.28	1027	1073	0.35
Mean	4.16	7.36	0.88	9.71	11.14	0.97	4.81	5.10	0.92	3.63	3.85	0.95	1226	2143	0.98	990	1128	0.96
Mean LSD[1]	2.72						0.80						431					
df	104						104						104					

[1]Mean LSD for rain-fed/irrigated mean values for both locations.
df, degrees of freedom; DSI, drought susceptibility index.

plant, secondary branches per plant, harvest index and seed : husk ratio. The percentage change in primary branches per plant was positively and significantly correlated with that of secondary branches per plant ($r = 0.550^*$) and harvest index ($r = 0.578^*$) at Bharatpur. However, the percentage change in seed yield and oil content were negatively and significantly correlated with each other ($r = -0.568^*$). At Jobner, no association between percentage change in characters was observed, as all the correlation coefficients were non-significant. The percentage change in seed weight at Bharatpur and Jobner was significantly related ($r = 0.585^*$). The DSI values for secondary branches per plant at Bharatpur and Jobner were positively correlated ($r = 0.827^{**}$). The DSI for the rest of the characters at both locations were not correlated. Nevertheless, a few genotypes like PSR-20 and JMMWR-941 were drought-tolerant at both locations. At Jobner, the DSI values for seed yield and plant height were positively correlated ($r = 0.538^*$). The absence of correlations for percentage change or DSI for characters between locations supports the existence of interactions among the genotypes and environments as suggested by the ANOVA/REML analysis. Furthermore, the change in seed weight and DSI for secondary branches per plant showing similar patterns of change at Bharatpur and Jobner, indicated that these characters could be taken as selection criteria for drought tolerance in Indian mustard.

Discussion

The reduction in 1000-seed weight under rain-fed conditions was marginally higher at Bharatpur (6.0%) when compared with Jobner (5.3%). However, genotype DIR-673 exhibited increased seed weight under rain-fed conditions at both locations, whereas few other genotypes had an increased seed weight at either location. Similar results have previously been reported by Sharma and Kumar (1989) as well as Singh and Singh (1991). The reduction in seed yield under rain-fed conditions among the different genotypes across both locations, which ranged between 4.3% and 60.0%, corroborate earlier findings where 17–94% yield reductions in mustard under moisture stress conditions were reported (Sharma and Kumar 1989, Mohamed Ali et al. 1990). Genotypes of *Brassica* species with drought-tolerance traits are known to produce the highest seed yield under drought conditions (Singh et al. 1988, Kumawat et al. 1997). The increase in harvest index observed in the present study could be due to reductions in total dry matter produced under rain-fed conditions (Mohamed Ali et al. 1990). In general, the reduction in most of the characteristics under rain-fed conditions, except for harvest index, seed : husk ratio and oil content, could be attributed to decreased translocation of assimilates and growth substances, impairing nitrogen metabolism, loss of turgidity and consequently reduced sink size (Kumawat et al. 1997). In the present study, depletion of soil moisture, which was associated with forced maturity during the pod-filling stage between January and March, might have resulted in decreased seed weight and seed yield. In general, the genotypes showed an increased seed : husk ratio under rain-fed conditions, except for RC-53, RC-1446, EC-347852 and PSR-20, suggesting that the translocation of assimilates from husk to seed might have been increased under rain-fed conditions.

The present study revealed that the top six drought-tolerant genotypes, as indicated by their relatively low DSI

Table 3: Harvest index and seed : husk ratio under rain-fed and irrigated conditions for different genotypes and their DSI at Bharatpur and Jobner (DSI values are not included in the statistical analysis)

	Harvest index (%)						Seed : husk ratio		
	Bharatpur			Jobner			Bharatpur		
Genotype	Rain-fed	Irrigated	DSI	Rain-fed	Irrigated	DSI	Rain-fed	Irrigated	DSI
IS-1787	31.6	29.8	0.37	27.5	32.4	−9.390	1.9	1.5	4.14
BE-3121	27.0	25.5	0.35	24.2	21.3	8.17	1.5	1.4	0.31
RC-53	28.7	27.8	0.19	24.4	23.9	1.28	1.4	1.6	−1.96
PRO-97024	30.6	25.7	0.15	24.7	22.9	4.74	1.8	1.7	1.02
RC-1446	32.4	29.1	0.68	23.8	22.4	3.84	1.5	1.5	−0.04
DIR-673	35.1	27.9	1.56	23.7	25.8	−4.86	1.8	1.5	3.05
RC-5	32.9	24.9	1.92	23.0	23.8	−2.07	1.9	1.4	5.78
EC-347852	27.3	30.0	−0.53	30.1	26.7	7.81	1.2	1.9	−6.3
JMMWR-941	32.4	30.5	0.37	21.1	20.3	2.42	2.0	1.8	1.55
PSR-20	30.2	21.5	2.41	23.4	20.6	8.34	1.4	1.6	−1.89
'Varuna'	32.8	28.9	0.8	23.2	22.7	1.35	1.6	1.6	0.51
PCR-7	30.1	22.8	1.93	22.2	18.0	14.35	1.7	1.4	3.27
RN-393	28.3	23.7	1.17	25.4	27.2	−4.13	1.5	1.4	1.03
RH-819	32.8	22.4	2.78	24.0	27.0	−6.81	1.7	1.2	7.91
Mean	30.9	26.5	1.00	24.3	23.9	1.79	1.6	1.5	1.31
Mean LSD[1]	4.7						0.4		
df	104						52		

[1]Mean LSD for rain-fed/irrigated mean values for both locations.
df, degrees of freedom; DSI, drought susceptibility index.

values for seed yield at either or both locations (Bharatpur and Jobner), were JMMWR-941, RC 1446, PSR 20, RH-819, 'Varuna' and RC-53 (Table 2). Tolerance to drought of seed yield was associated with tolerance to drought of plant height, 1000-seed weight, primary branches per plant, harvest index and seed : husk ratio. The present study also revealed that high seed : husk ratio and harvest index may too merit consideration for identifying or developing suitable genotypes for drought stress conditions, besides the high seed weight and more branches per plant (Singh 1986). Singh and Choudhary (2003) used DSI values and seed yield under drought conditions as a selection criterion for drought tolerance in Indian mustard. Donors with multi-characteristics for drought tolerance should therefore be utilized in breeding programmes. Genotypes with the lowest DSI, particularly for seed yield, at both locations such as PSR-20 (DSI = 0.29) and JMMWR-941 (DSI = −0.27) would serve as useful donors for improving the drought tolerance of existing Indian mustard cultivars.

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